UDC 004.94:53:371.3

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VISUALIZATION OF MODELING PHYSICAL LAWS FOR SYSTEMS, PROCESSES AND PHENOMENA USING AUGMENTED REALITY

DOI: 10.14308/ite000738

The methods of visualization in modeling physical laws for systems, processes and phenomena using AR technologies in the educational process of secondary schools are considered. The use of augmented reality (AR) technology allows teachers to design and create effective educational resources (EER). Visual representation of the action of physical laws contributes to their better perception and understanding by students and increases their motivation to learn.

A model of an educational system using augmented reality technologies was built to visualize physical laws in school textbooks. Examples of visualization of physical laws in the 8th grade physics course were considered. AR applications were developed to visualize physical laws studied in the sections "Thermal phenomena", "Electrical phenomena. Electric current".

The expert method was used to assess the prospects for using augmented reality in the educational process. The result of a survey of experienced secondary school teachers in Kherson (Ukraine) confirmed the hypothesis about the effectiveness of using electronic educational resources based on AR technology. The feasibility of using such educational resources both in the classroom at school and in extracurricular work during independent learning has been confirmed. The proposed model of the learning system was tested in the classrooms of students in the process of studying in the specialties of the STEM educational paradigm.

Keywords: *Augmented reality, ICT, mobile application, visualization, physical laws, school textbook*

1 Introduction

One of the effective methods for studying physical laws is the visualization of models of systems, processes and phenomena in which they operate. When studying physical laws in a school physics course, methods of their description, physical and mathematical modeling, laboratory work and solving practical problems, visualization in the form of drawings, photographs, diagrams, multimedia software objects and video films are used. Visualization of the elements of physical systems, the values of their parameters, initial, current and final data allows you to visualize the object or process under study. Visualization of dynamic systems and physical processes is based on the visualization of the development of systems in time.

The modeling is based on physical and mathematical modeling of systems and processes, including physical laws [1]. These models are used for software design [2].

The Physics Educational Complex "Fascinating Reality" is a digital interactive teaching aid for studying physics with an increased level of involvement in the educational process through augmented / virtual reality technologies, three-dimensional graphics and 3D stereoscopy. From the methodological point of view, the complex has implemented more than 100 demonstrations and virtual laboratory works on key topics of the school physics course, in which more than 300 interactive animated 3D models are used [3].

Augmented reality is a type of virtual reality technology that combines objects and processes in a real environment with digital content created by computer software. The introduction of new approaches to the educational process and the use of new technologies are aimed at improving the quality of students' knowledge and skills.

Augmented reality allows you to study the operation of various dynamic and static systems, expanding the boundaries of reality, which in turn helps to increase students' interest in the subject of the studied area, better assimilation of new information.

AR methods and technologies are used to visualize the state and interaction of various static and dynamic systems, expanding the boundaries of reality. This increases students' interest in the subject of the studied area and the level of assimilation of theoretical material.

The relevance of creating and using EER using AR in secondary and higher education is determined by the need for a wide range of disciplines for:

- visualization of models of systems and processes,
- detailing the presentation of properties and interaction of complex objects,
- visualization of the interaction of elements of complex objects,
- creation and implementation of virtual excursions and travels, etc.

The subject of the study is the modeling and design of ERR software and hardware using interactive augmented reality technologies.

The aim of this work is to design and develop ERR software for visualization of processes and models of physical laws using AR.

Analysis of methodological approaches to application and a detailed description of the toolkit for developing ERR software using augmented reality can be found in the article [4].

Visualization of systems, processes and phenomena under the conditions of the action of physical laws is especially effective when using AR technologies.

An architecture of this system is shown in Figure 1 [4].

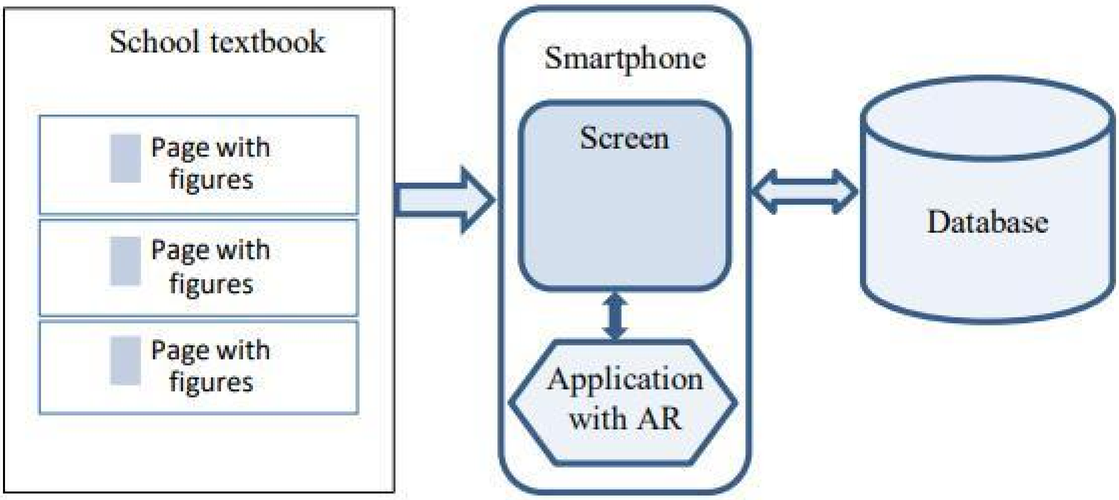

Figure 1. An architecture of EER using augmented reality

School textbook is the main teaching resource in the learning system. Images, figures in a school textbook can serve as a trigger for visualizing models of existing objects that the user sees on the smartphone screen as a result of the application. An e-book can also be used, which is the publication of a book in digital form.

Smartphone is a mobile device with the required OS parameters (Android or IOS version, camera, Internet access) and with the AR application installed.

Database is used for external storage of training resources and is an important element of the training system.

Before creating an augmented reality (AR) training system, it is necessary to develop a plan of the application scenario, which should include the following components:

- development of an AR physics ERR begins with the creation of a plan of the scenario for visualizing the physical process, which should include the following components:
- multimedia and interactive elements of the visualization system;
- description of user interaction with the content: user interaction is carried out through data exchange with the system server (the user can download the necessary resources, as well as enter data during testing);
- description of user interaction with the content through data exchange with the system server (the user can download the necessary resources, as well as enter data during the use of the ERR);
- requirements and conditions for the use of additional software necessary for working with the ERR;
- user-friendly interface for using the application.

2. Description of the Learning System Model Using AR Technology for Visualization Physical Lows

2.1 The subject area

Table 1 shows the list of sections studied according to the physics course program 7-9, 10-11 [5]. For each section, there is a list of the physical laws studied in this section.

Table 1. *The list of sections and physical laws according to the program of a course of physics of 7-11 grades*

#	Grade	List of sections	List of physical laws
1	7	"Physics as a natural science. Cognition of nature", "Mechanical motion", "Interaction of bodies. Force", "Mechanical work and energy"	Hooke's law. Pascal's law. Archimedes' law. Law of energy conservation.
2	8	"Thermal phenomena", "Electrical phenomena. Electric current"	The law of heat transfer. Coulomb's law. Ohm's law for a section of a circle. Joule-Lenz law.
3	9	"Magnetic phenomena", "Light phenomena", "Mechanical and electromagnetic waves", "Physics of the atom and the atomic nucleus. Physical foundations of nuclear energy", "Movement and interaction. Laws of conservation"	Law of direct light propagation. Reflection law. Refraction law. Newton's laws. Newton's law of universal gravitation. Momentum conservation law.
4	10	"Mechanics", "Molecular Physics and Thermodynamics"	Law of velocity composition. Newton's laws. Law of universal gravitation. Pascal's law. Archimedes' law. Bernoulli's law. Momentum conservation law. Law of conservation of angular momentum.

5	11	"Electrodynamics", "Oscillations and Waves", "Quantum Physics"	Coulomb's law. Ohm's law for a complete circuit. Joule-Lenz law. Law of electromagnetic induction. Laws of electrolysis. Faraday's law. Huygens' principle. Reflection and refraction laws. Doppler effect. Laws of geometric optics. Laws of motion in quantum physics. Heisenberg's principle. Radioactive decay law.

Physical laws in the school physics course are studied by the method of their description, physical and mathematical modeling, laboratory work and solving practical tasks. Therefore, to visualize their models in physical modeling, it is necessary to present a description of the physical system in which the physical law operates, in the form of the interaction of its visual elements. At the same time, the physical parameters of these interacting elements of the system can form functional relationships in the form of a set of mathematical formulas. These formulas in the form of equations, inequalities and their systems form a mathematical model of a physical system.

As an example, consider the laws of physics in the 8th grade physics course. The program of the 8th grade of the school curriculum of physics contains two sections of physics: 1. "Thermal phenomena" and 2. "Electrical phenomena. Electricity". In the learning module "Electric current" when studying Ohm's law for a section of a circuit to demonstrate the operation of the law, you can use the electric circuit diagram Exercise 29.1 [6] (Figure 2).

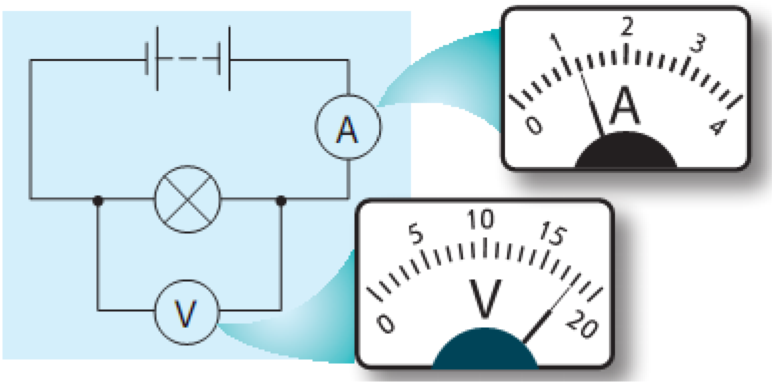

Figure 2. *An electrical circuit to visualize the action of Ohm's law for a section of the circuit*

The system model consists of an electrical circuit containing the elements: a current source with voltage *U*, a lamp with resistance *R*, instruments - a voltmeter and an ammeter. The mathematical model is determined by the formula (1) of the dependence of the current strength *I* on the voltage *U* and resistance *R*.

$$I = \frac{U}{R} \qquad \textbf{(1)}$$

Parameters *U* and *R* are set, and the value of parameter *I* is calculated according to (1). For example, with $U = 18$ V and $R = 3\ \Omega$, we get the calculated value $I = 6$ A.

2.2 Learning System Model

The formal model M of the physical laws visualization system can be represented in the form (2).

$$\mathrm{M} = (\sigma, \mu(\sigma), \Sigma(\sigma), \Phi(\mu(\sigma))) \qquad \textbf{(2)}$$

where $\sigma = (\sigma_1, \sigma_2, \ldots, \sigma_k)$ is the set of system elements, $\mu(\sigma) = (\mu(\sigma_1), \mu(\sigma_2), \ldots, \mu(\sigma_k))$ is the set of parameters of the system elements, $\Sigma(\sigma)$ – the formula for the connection of the elements σ [7], $\Phi(\mu(\sigma))$ – a set of formulas of the mathematical model depending on the parameters $\mu(\sigma)$.

2.3 Samples

Let's consider examples of the model representation of the physical laws visualization system of the 8th grade physics course.

Example 1. Coulomb's law.

The formulation of Coulomb's law: The force F of the interaction of two stationary point charges q_1 and q_2 is directly proportional to the product of the absolute value of these charges and inversely proportional to the square of the distance r between them (3):

$$F = k\frac{|q_1| \cdot |q_2|}{r^2} \quad (3)$$

where $k = 1/(4\pi\varepsilon_o\varepsilon)$ is the proportionality coefficient, $\varepsilon_o = 8{,}85*10^{-12}$ $C^2/N*m^2$ is the electrical constant, ε – is the dielectric constant of the medium.

The formal model M_1 of the Coulomb's law visualization system in accordance with (2) has the form (4):

$$M_1 = (\sigma = (\sigma_1, \sigma_2), \mu(\sigma), \Sigma(\sigma), \Phi(\mu(\sigma))) \quad (4)$$

where σ_1 is point charge 1, $\mu(\sigma_1) = (q_1, F_1, m_1, l_1, r)$, σ_2 is point charge 2, $\mu(\sigma_2) = (q_2, F_2, m_2, l_2)$, m_i is the mass of a point charge i, l_i is the length of the inextensible thread on which the point charge i (i = 1,2), $\Sigma(\sigma)$ is the formula for the connection of the elements σ_1 and σ_2, in accordance with Figure 3.

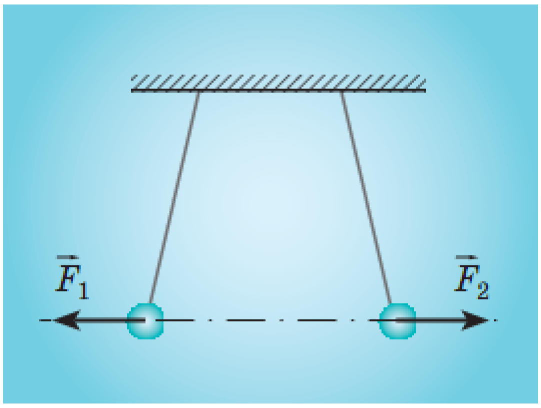

Figure 3. The forces F_1 and F_2 of the electrical interaction of point charges are directed along the conditional straight line connecting these charges

The mathematical model $\Phi(\mu(\sigma))$ is built on the basis of formula (3), setting the values of the parameters q_1, q_2, in one system of units (for example, SI) to calculate the value of F.

Example 2. Ohm's law.

The formulation of Ohm's law for the circuit section:

The current in a section of the circuit is directly proportional to the voltage at the ends of this section and inversely proportional to the resistance of this section (5):

$$I = \frac{U}{R} \qquad \textbf{(5)}$$

where U is voltage, R is resistance, I – current.

The formal model M_2 of the Ohm's law visualization system in accordance with (2) has the form (6):

$$M_2 = (\sigma = (\sigma_1, \sigma_2, \sigma_3), \mu(\sigma), \Sigma(\sigma), \Phi(\mu(\sigma))), \qquad \textbf{(6)}$$

where σ_1 is a voltmeter, $\mu(\sigma_1) = U$, σ_2 is a lamp, $\mu(\sigma_2) = R$, σ_3 is an ammeter, $\mu(\sigma_3) = I$, $\Sigma(\sigma)$ is the formula for the connection of the elements σ_1, σ_2 and σ_3, in accordance with Figure 2.

The mathematical model $\Phi(\mu(\sigma))$ is built on the basis of formula (5), setting the values of the parameters U and R in one system of units (for example, SI) for calculating I.

3 Software Design for Visualization Physical Lows Using AR Technology

An application for visualizing physics laws using AR has the following interface components:

- "View object" (trigger scan to launch the application),
- "Application screen" (work area of the application),
- "Parameters panel" (input of values of parameters of a physical system or process, control of navigation through the application),
- "Help" (instructions for using the application),
- "Exit" (exit from the application).

When you point the camera lens at the page with a special marker, the program recognizes the trigger mark and launches the corresponding mobile application.

The user can perform control and navigation actions. At the time of performing a certain action with objects, the user in the background can see the corresponding contextual help and training information.

To use the program for its intended purpose, the user must have a textbook with triggers and a smartphone with AR apps.

Let us consider in more detail the process of modeling and design of educational objects AR using the example of visualization of models of physical processes under the conditions of the action of physical laws.

As an example, consider a school textbook in physics for grade 8 edited by V.G. Baryakhtar, S.O. Dovgy [6], section "Electrical phenomena. Electric current", § 22. Coulomb's law, page 121. An example of an illustration of the operation of Coulomb's law is considered in the textbook (Figure 3) as a trigger #1 (variable notation retained).

In Unity 3D, Vuforia, a 3D model was developed for trigger # 1. It consists of the following elements: σ_i - point charge i (i = 1,2), $\mu(\sigma_1) = (q_1, F_1, r)$, $\mu(\sigma_2) = (q_2, F_2)$.

The user can change the values of the charges q_1 and q_2 for a given distance r between them. The calculated value of the force of interaction of charges illustrates the action of Coulomb's law (Figure 4).

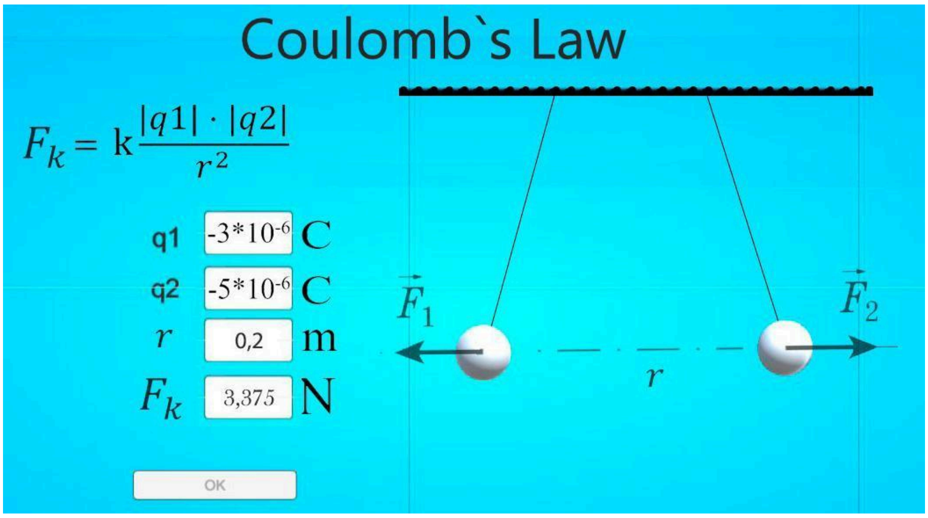

Figure 4. Visualization of the Coulomb's law using AR

Consider the following example, demonstrating the Ohm's law, # 29 from the school textbook [6] (Figure 2). Unity 3D with Vuforia has developed a 3D model for the trigger Figure 2. It consists of the following elements: σ_1 is a voltmeter V, $\mu(\sigma_1) = U$, σ_2 is a lamp L, $\mu(\sigma_2) = R$, σ_3 is an ammeter A, $\mu(\sigma_3) = I$.

At the given values of voltage U and resistance R, the ammeter shows the value of the current I calculated by the formula (5) (Figure 5).

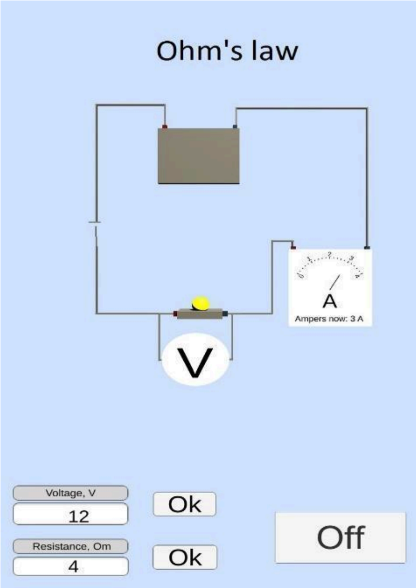

Figure 5. Visualization of the Ohm's law using AR

An on / off switch connects and opens the circuit, thereby updating the calculated data.

4 Prospects for using AR in the educational process

The expert method was used to assess the prospects for using augmented reality in the educational process. The results of a survey of 12 experienced secondary school teachers in Kherson (Ukraine) confirmed the hypothesis of the effectiveness of using electronic educational resources based on AR technology. The feasibility of using such educational resources both in the classroom at school and in extracurricular work during independent learning was confirmed.

The results of the evaluation of indicators are presented in Table 2.

Table 2. *Expert assessment of ERR using AR technologies*

#	Evaluation Options	Grade
1	ERR is consistent with the curriculum	3,5
2	The use of ERR is methodologically justified	4,8
3	The use of ERR is technologically justified	4,2
4	ERR has the property of interactivity	4,1
5	ERR has a convenient user interface	3,9
6	The use of ERR motivates students	4,5
7	ERR can be used in classrooms	3,3
8	ERR can be used for independent work	4,7
9	Teachers are interested in using ERR	3,9
10	I plan to use such ERR in the educational process	3,5

Thus, the results of the teacher survey confirm the relevance and importance of designing and creating EER using AR-powered apps.

5 Conclusion and future work

The relevance of creating EER based on AR technologies is determined by their wide use in the learning process in secondary and higher education.

The paper proposes a model for visualizing systems and processes to demonstrate the action of physical laws. The development technology and methodology for using software based on augmented reality are described.

The proposed model of the training system formed the basis for the design and development of EER for visualizing physical laws in the 8th grade physics course and was tested in the learning process in STEM disciplines. Augmented reality applications were developed to visualize physical processes studied in the sections "Thermal Phenomena", "Electrical Phenomena. Electric Current".

An expert method was used to assess the prospects for using augmented reality in the educational process. The results of a survey of experienced secondary school teachers in Kherson (Ukraine) confirmed the hypothesis about the effectiveness of using electronic educational resources based on augmented reality technology.

The developed model for visualizing systems and processes can be used as a basis for developing EER for a wide range of disciplines in secondary and higher education.

REFERENCES (TRANSLATED AND TRANSLITERATED)

1. Albert Benveniste, Benoît Caillaud, and Mathias Malandain. (2020) The Mathematical Foundations of Physical Systems Modeling Languages. Research Report RR-9334. Inria. 112 pages. Retrieved from https://hal.inria.fr/hal-02521747.
2. Januszka M., Moczulski W. (2010) Augmented Reality for Machinery Systems Design and Development. In: Pokojski J., Fukuda S., Salwiński J. (eds) New World Situation: New Directions in Concurrent Engineering. Advanced Concurrent Engineering. Springer, London, online https://doi.org/10.1007/978-0-85729-024-3_10.
3. Physics Educational Complex "Fascinating Reality". Ltd "Internet for Life". Certificate of State registration of a computer program – N2014614575 “Educational-methodical complex for

conducting virtual laboratory work on the school physics course "Fascinating Reality". Version 2.0, online https://funreality.ru/lp.

4. Hennadiy Kravtsov, Anastasiia Pulinets. Interactive Augmented Reality Technologies for Model Visualization in the School Textbook. In: Proc. 16th Int. Conf. on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer (ICTERI2020). Volume II: Workshops, Kharkiv, Ukraine, October 06-10 (2020). CEUR-WS.org, Vol. 2732, p. 918–933, online, http://ceur-ws.org/Vol-2732.

5. Physics, grades 7–9, 10–11. Educational program for general educational institutions. Available at: https://mon.gov.ua/ua/osvita/zagalna-serednya-osvita/navchalni-programi.

6. Physics: 8th grade textbook ed. Baryakhtar V.G., Dovgy S.O. Kharkov: Publishing House "Ranok", 240 p. (2016).

7. Lvov M., Kuzmenkov S., Kravtsov H. System for Testing Physics Knowledge. In: Ermolayev V., Mallet F., Yakovyna V., Mayr H., Spivakovsky A. (eds) Information and Communication Technologies in Education, Research, and Industrial Applications. ICTERI 2019. Communications in Computer and Information Science, vol 1175. Springer, pp 186–209, Cham. Online https://link.springer.com/chapter/10.1007/978-3-030-39459-2_9 (2020).

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ВІЗУАЛІЗАЦІЯ МОДЕЛЮВАННЯ ФІЗИЧНИХ ЗАКОНІВ СИСТЕМ, ПРОЦЕСІВ ТА ЯВИЩ ЗА ДОПОМОГОЮ ДОПОВНЕНОЇ РЕАЛЬНОСТІ

Розглянуто методи візуалізації при моделюванні фізичних законів для систем, процесів та явищ за допомогою AR-технологій у навчальному процесі середньої школи. Використання AR-технології дає змогу проектувати та створювати ефективні навчальні ресурси. Візуальне представлення дії фізичних законів сприяє їх кращому сприйняттю і розумінню учнями та підвищує їхню мотивацію до навчання.

Для візуалізації фізичних законів у шкільних підручниках побудована модель навчальної системи з використанням технологій доповненої реальності. Розглянуто приклади візуалізації фізичних законів у курсі фізики 8 класу. Розроблено AR-додатки для візуалізації фізичних законів, що вивчалися в розділах «Теплові явища», «Електричні явища. Електричний струм».

Експертний метод застосовано для оцінки перспектив використання доповненої реальності в освітньому процесі. Результат опитування досвідчених вчителів середніх шкіл Херсона (Україна) підтвердив гіпотезу про ефективність використання електронних навчальних ресурсів на основі AR-технології. Підтверджено доцільність використання таких навчальних ресурсів як у класі в школі, так і у позакласній роботі під час самостійного навчання. Запропонована модель системи навчання була апробована в аудиторіях студентів у процесі навчання за спеціальностями освітньої парадигми STEM.

Ключові слова: доповнена реальність, ІКТ, мобільний додаток, візуалізація, фізичні закони, шкільний підручник

Стаття надійшла до редакції 10.02.2021
The article was received 10 February 2021